NOAA Research Project

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"Optimal Use of the Climate Prediction Center's Long-Lead Outlooks: Improved Interpretability and Decision-Analytic Case Studies"

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Summary of Research Results

a) Previous Years

The Principal Investigators have been involved in a number of projects relating to the interpretation, use, and value of seasonal forecasts, both from CPC and IRI, in the past three years, supported by NOAA/OGP/HDGCR under grant NA86GP0555. In addition, related research on electricity markets has been supported in the Power System Engineering Research Center by the Transmission Reliability Program of the U.S. Department of Energy. Results obtained from this research include the following:

• Diagnostic verification of seasonal forecasts: Comprehensive analyses of the performance characteristics of recent seasonal forecasts were completed, using diagnostic verification methods (examination of the joint frequency distributions of forecasts and observations, as functions of forecast variable, lead times and geographic locations). Parallel studies were undertaken for both the NOAA/CPC forecasts (Wilks, 1999a; Wilks, 2000b), and the IRI forecasts (Wilks and Godfrey, 2000; Wilks and Godfrey, 2002a; Wilks and Godfrey, 2002b). The CPC forecasts exhibited strong cool and dry biases, apparently related to the fact that the 1995-98 forecast period was markedly warmer and wetter over the US than the 1961-1990 reference period. However, both temperature and precipitation forecasts exhibited substantial resolution, implying a higher information content than might be inferred from examination of simple scalar skill scores. The (global) IRI forecasts exhibited similar cool and dry biases, again apparently related to relatively warm and wet conditions not being well forecast in aggregate. Forecasts for low latitudes were much more skillful than for mid- and high latitudes, especially for precipitation.

• Enhanced interpretation of seasonal forecasts, relating to the “tercile” format: Both the CPC and IRI forecasts consist of probabilities for three temperature or precipitation classes, which format may be difficult for some to interpret, and which is less than ideal as input to some decision problems. The overlapping 3-month format of the CPC (and now also the IRI) forecasts was analyzed (Wilks, 2000a, 2000c), and found to almost fully imply a sequence of monthly forecasts comprising the time period of the overlapping seasons, but the web of dependencies among them imply that self-consistent sets are very difficult for forecasters to produce. Therefore simultaneous use of more than one seasonal forecast in a given sequence should be undertaken with caution. Also presented in Wilks (2000a) are procedures to transform the discrete, three-category probability forecasts for temperature and precipitation to smooth probability distributions over the full range of the predictands, allowing use of the forecasts in decision problems involving temperature or precipitation thresholds at any user-specified level rather than the 1/3- or 2/3 points of the climatological distributions.

• Space-time downscaling of seasonal forecasts ("weather in climate"): Currently available seasonal forecasts are highly aggregated in both time (seasonal averages) and space (hundreds or thousands of km of uniform probability anomalies), whereas some potential uses of the forecasts (e.g., hydrological or crop forecasting) require site-specific realizations of daily series. The implications of seasonal and/or temperature probability anomalies on the parameters of "weather generator" models have been determined (Wilks, 2001, 2002), which allows stochastic generation of arbitrarily many realizations of daily weather sequences consistent with a particular forecast, at a spatial network of locations. These can be use to drive response models to yield probability distributions over relevant responses consistent with a particular seasonal forecast.

• Applications of the space-time disaggregation: The translation of seasonal forecast probabilities into altered weather generator parameters has been used to date in two climate-sensitive case studies. Ning, Mount, and Wilks, (2002) and Ning, (2001) showed how the relatively small shifts of average seasonal temperature between "extreme" and "normal" CPC forecasts can be amplified in some situations through their effects on implied daily weather series to provide substantial shifts in the predicted prices of electricity in restructured markets. The reason is that a large contributor to high seasonal-average electricity prices is the existence of short-term price spikes, the frequency of these is greatly enhanced on hot days, and the probability of an extremely warm day increases more quickly than the corresponding shift in mean. Essentially, substantial shifts in the frequency distribution for extremely hot days are very sensitive to, and diagnosed from, the seasonal-average temperature forecasts. In the second sequence of studies (Meza et al., 2002, 2003; Meza and Wilks, 2003), the utility of both perfect and simple (practically realizable) statistical forecasts of Nino 3.4 sea-surface temperatures on agricultural decisions in Chile are investigated. Calculated economic value depends very sensitively on the location within Chile and the crop under consideration, but range from zero to more than $100/ha-yr in certain cases, even for the imperfect forecasts. These are among the highest economic values for seasonal forecasts reported in the literature to date.

• Testing the performance of electricity markets: Restructured markets for electricity generally use a specified type of auction to determine prices. Offers to sell power are submitted to an Independent System Operator (ISO) and some form of security constrained dispatching algorithm is used to minimize the cost of meeting the load. Our research has used experimental economics extensively to test the competitiveness of different types of auction. In a uniform price auction (the standard auction used in electricity markets), we have duplicated the type of price volatility found in restructured markets when load is perfectly inelastic (i.e., a given load must be met regardless of the price.). We have also shown that price responsive load is a more effective way to lower average prices and reduce price volatility than adopting other types of auction (i.e. the soft-cap auction used in California during the first few months of 2001, see Mount et al., 2001 and 2002).

b) Current Research on the Role of Weather Derivatives in Electricity Markets

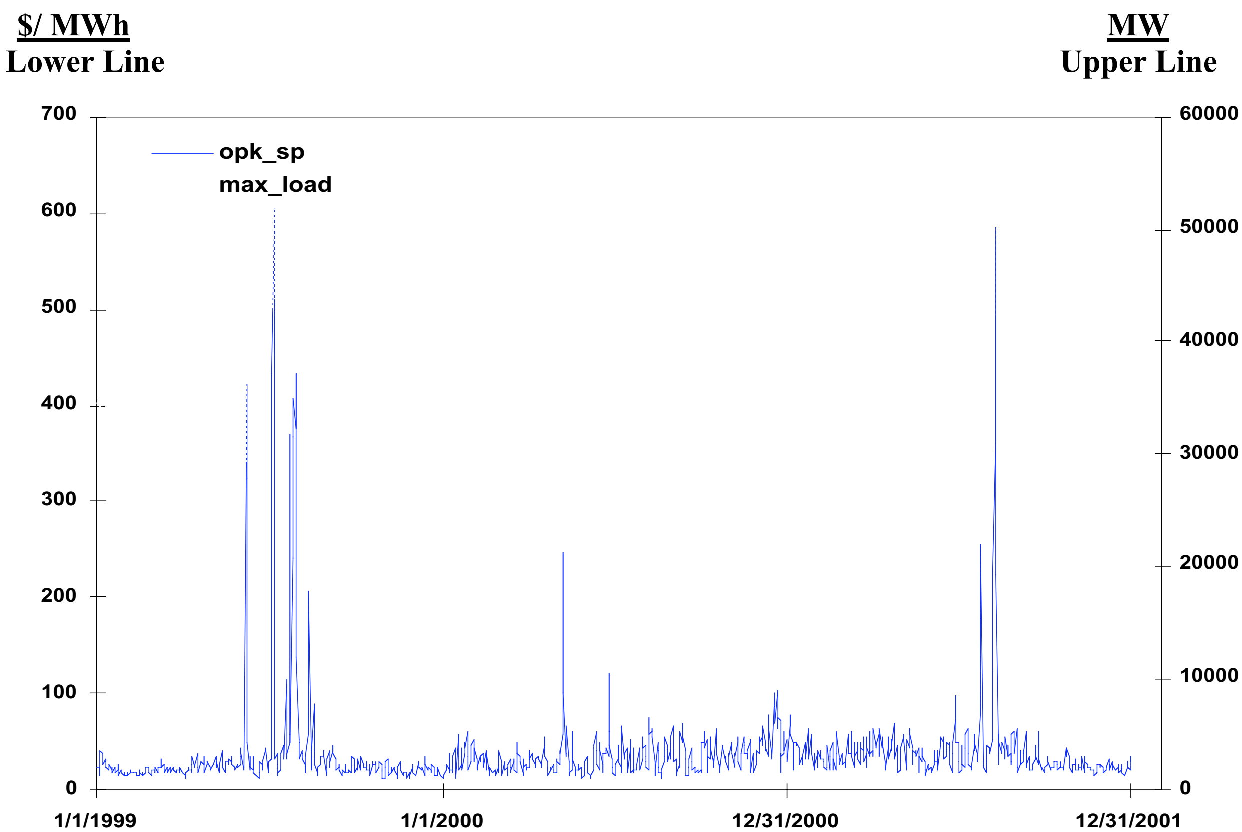
The relationship between temperature and the demand (load) for electricity is well understood (Ramanathan et al, 1997; Bunn, 1999, 2000). Using relatively simple forms of ARIMA models (Box and Jenkins, 1976), it is possible to predict daily maximum load for PJM with a 1-2% forecasting error using temperature as an input variable (Ning, 2001). An innovation of our previous research was to predict the daily spot price of electricity (average for the sixteen-hour peak) using a regime switching model (Hamilton, 1994; Ethier, 1999; and Ethier and Mount, 1999). One regime has a low average price with a small variance and the other has a high average price with a large variance. The probabilities of switching from one regime to another are determined by Markov probabilities. This model was extended to include load or forecasted load as an explanatory variable (Ning, 2001; Ning, Mount and Wilks, 2002). In particular, the probability of switching to the high price regime (i.e. observing a price spike) is positively related to the load, and therefore, also to temperature in the summer. Nevertheless, the probability of getting a price spike is only about 60% for PJM in the summer 1999 at the highest load. Hence, the predictability of individual price spikes is relatively low compared to the predictability of load.

An important finding from our research is that relatively small shifts in the average temperature for a summer associated with different CPC Outlooks can have a relatively large effect on the average price over a summer. Using a sample of realizations of daily temperature sequences that are consistent with a specific CPC Outlook, it is possible to predict the corresponding patterns of load and price. A comparison of the predictions under normal and high (extreme) temperature conditions was made using the models for PJM in the summer 1999. (There were a large number of price spikes during this period.) Even though the increases in the mean temperature (1.3°F) and the mean load (2.3%) are small, the increase of the mean price (20%) is substantial. This demonstrates how effectively the signal from the CPC Outlook is amplified by the non-linear relationship between load and price. Related research has investigated the shape of the offer (supply) curves submitted by suppliers into the PJM market. The "hockey-stick" shape of supply (most capacity is offered at prices less than $50/MWh, but a few units are offered at prices up to $1000/MWh, (see Mount, Ning and Oh, 2000) is consistent with a regime-switching model for prices.

The behavior of suppliers, in terms of the shape of the supply curve, did not change in the summer 2000 even though there were very few price spikes (see Figure 1). The reason was that temperatures and loads were relatively low. However, the potential for getting price spikes was still there. Price spikes were observed again in August 2001 when high temperatures occurred. Price spikes are an anathema to many regulators. Regulatory interventions in California by the Federal Energy Regulatory Commission (FERC) and in New York State by the New York Public Service Commission have introduced cumbersome procedures for suppressing price spikes. These efforts tend to reduce the effectiveness of price signals as a way to discipline markets (i.e.

high prices should reduce load, shift load to off-peak periods and increase supplies). The basic objective of the new research project is to demonstrate that it is possible to hedge against the risk of high prices and uncertain load if 1) forward contracts for electricity are specified appropriately, and 2) these contracts are combined with weather derivatives. With this type of portfolio, price signals in the spot market are still effective, and customers can reduce their bills substantially if they conserve on hot days when prices are high.

Figure 1: Daily Maximum Load and Day-Ahead On-Peak Price in PJM (January 1999 – December 2001)



Modeling Temperature

At least two groups currently produce operational, public-domain monthly and seasonal forecasts for temperature and precipitation: the Climate Prediction Center (CPC) of the U.S. National Centers for Environmental Prediction (Barnston et al., 1999, http://www.cpc.ncep.noaa.gov/), and the International Research Institute (IRI) for Climate Prediction at Lamont-Doherty Earth Observatory (Mason et al., 1999, http://iri.ldeo.columbia.edu/). Both groups issue forecasts in the "tercile" format, specifying probabilities for each of the three climatological categories defined by the lower (1/3-point) and upper (2/3 point) terciles of the climatological distribution relevant to the forecast variable, geographic location, and season in question. This format has been adopted, consistent with the needs of forecasting operations and currently achievable levels of forecast resolution, and issues related to the interpretation of such forecasts are presented in Wilks (2000a).

A convenient and flexible method to produce realizations of synthetic (but realistic) weather series is through stochastic models of weather data known as "weather generators" (Richardson; 1981, Wilks and Wilby, 1999). The feasibility of simulating electricity load in the northeastern U.S. has been demonstrated using simultaneous realizations of daily maximum and minimum temperatures, at Boston, New York City, Allentown, Philadelphia and Washington. Existing methods (Wilks, 1999b) were used to ensure that the simultaneous time series for the five locations exhibit realistic spatial correlations to ensure that loads in the three northeastern power pools can be modeled accurately.

Results from our prior research (Wilks, 2002) can be used to adjust weather generator parameters, and thus produce joint realizations of daily weather, consistent with particular realistic CPC summer temperature outlooks. Even though the seasonal outlooks do not, and cannot, predict particular sequences of daily data, the seasonal averages that they do predict are summaries of the integrated effects of the individual days in that season. For example, if the forecasted probability distribution for average seasonal temperature is shifted upward relative to the climatological distribution, it is inevitable that the corresponding statistics for the daily weather must be shifted upward as well, and it is possible to calculate the link between the two time scales. Accordingly, synthetic realizations of daily temperature time series for any location that are consistent for any particular seasonal temperature forecast can be generated. From these one may tabulate probability distributions for such daily statistics as cooling degree-days (CDD), or number of days above significant temperature thresholds, which may be useful bases for financial instruments relevant to hedging risk in electricity markets. Furthermore, these simulations can be carried out simultaneously for a collection of locations (e.g., cities in the Northeastern U.S.) in a way that preserves the substantial spatial correlations of daily temperature: the synthetic series, for example, exhibit the same tendency for hot days to occur simultaneously in the selected cities, that occurs in the real world. However, demonstrating that these methods can be used effectively for specific electricity markets will be part of a future research.

Modeling Load and Price

Given realizations of the summer patterns of temperatures for different locations, the next step is to determine the corresponding patterns of load and price for each location. In our previous research, the model structure for forecasting the load and the price was sequential. Temperature was used in an ARMAX model to determine load, and then load was used in a stochastic regime-switching model to determine price. These models for load in PJM performed well, and they explained over 95% of the variability of day-ahead forecasts (see Ning, 2001). The models for price replicate the general behavior of prices well (i.e. exhibit price spikes), but the highest probability of getting a price spike on a specific day is still relatively low (0.6) for forecasting purposes. Nevertheless, it is the behavior of prices over a summer that matters in our analysis, and it is not necessary to be able to predict on which days price spikes occur. It is more important to predict the number of price spikes accurately, and in this respect, the regime switching model is satisfactory.

An important problem for modeling price behavior is that the structure of markets often changes substantially. For example, PJM replaced a one-settlement market with a two-settlement market in 2000. It will be important to use new data to re-estimate the models for price to represent the current structures of the markets. When satisfactory models for load and price have been estimated from observed market data, it is straightforward to use these estimated relationships to compute the loads and the spot prices corresponding to samples of realizations of temperature that follow from the different seasonal outlooks. These will provide the basis for determining the levels of risk for selected metrics which can be studied as functions of seasonal outlooks, and unconditionally on the basis of retrospective climate information only. The same temperature data and forecasts of load will be used to evaluate the risk of different forward contracts for electricity.

Designing Forward Contracts for Electricity

Sample realizations of temperature, load and spot prices in PJM have been used to measure the financial risk associated with the total cost of purchasing electricity in the wholesale market over a summer. An underlying issue, however, is that average temperature and price are not highly correlated. Consequently, typical derivatives based on Cooling Degree Days (CDD), for example, do not provide an effective hedge against the risk of purchases in the wholesale market. Our research on designing contracts has already shown how to improve the effectiveness of weather derivatives (Mount, 2002; Mount and Yoo, 2002). The approach taken is to modify both the standard type of contract for buying electricity and the standard CDD derivative.

In a simplified market with only two levels of load associated with hot and cool days, the main source of risk is the random number of hot days. If high prices are more likely to occur on hot days when the load is high, then the spot market for electricity is very volatile. Assuming that a representative Distribution Company (DISCO) buys electricity in the spot market and sells to customers at a fixed rate set by regulators, then it is likely, using the specifications in the example, that losses will occur in many summers even though average returns are positive. The Generating Company (GENCO) faces similar volatility in the spot market but rarely loses money, given the assumptions about production costs.

Using the form of contract proposed by Wu, Kleindorfer and Zhang (2000) for variable load (e.g. caused by the uncertainty of temperature) suppliers require a large fixed (lump sum) payment and also charge a price for each unit purchased. Risk is reduced because the price per unit is relatively low compared to the average spot price. It is assumed that the DISCO and the GENCO will accept a forward contract for electricity only if both benefit. Since the GENCO has a better bargaining position, the average contract price is always higher than the average price in the spot market. However, risk is reduced with the contract, particularly for the DISCO. In fact, the DISCO prefers a small average loss with no volatility to a small average profit with a lot of volatility.

There are two important problems with the forward contract. First, it does not reduce the overall average price (including the fixed payment); and second, it hides the high prices in the spot market when they occur. Consequently, the ability of market forces to mitigate high prices on hot days is undermined. The frequency of the high prices is the major determinant of total cost in the spot market and the major source of risk to both the DISCO and the GENCO. Since hockey-stick offers in real markets imply high price elasticities of supply in the high-price regime, price-responsive load can be a very effective way to lower average prices and lower price volatility (see Mount, et al, 2001; Mount, et al, 2002). Hence, it is sensible from the perspective of economic efficiency to ensure that demand conservation is rewarded by substantial savings in costs. This happens when customers have to pay the high prices.

The proposal made by Mount (2002) and Mount and Yoo (2002) is to charge a high price for electricity on hot days in a forward contract and a low price for electricity on other days. Hence, the high load on hot days is always expensive. This contract is not attractive on its own, particularly to the DISCO, because the total cost of purchases is more volatile than the spot market. However, the associated increase of risk can be hedged effectively by a weather derivative based on the number of hot days in the summer. In the example, all risk can be hedged perfectly, and both the DISCO and the GENCO benefit from the combined contracts. In contrast, a conventional CDD weather derivative is not nearly as effective for hedging against the cost of direct purchases in the spot market. It is interesting to note that a pricing program of this type has been operating successfully in France since 1996. Under this program, there are three types of days that are announced in advance (high prices on red days, moderate prices on blue days and low prices on white days, which are by far the most numerous). The estimated price elasticity of demand for on-peak demand is surprisingly high (-0.79) (see Faruqui and George, 2002). This high elasticity demonstrates the potential for making load response on hot days an effective way to reduce average spot prices and make the market more competitive.

References

Alaton, P., B. Djehiche, and D. Stillberger, 2002. On Modelling and Pricing Weather Derivatives. <http://www.energyforum.net/downloads/reports/fat_1.pdf>.

Barnston, A.G., A. Leetmaa, V.E. Kousky, R.E. Livezey, E.A. O'Lenic, H. van den Dool, A.J. Wagner, and D.A. Unger, 1999. NCEP forecasts of the El Nino of 1997098 and its U.S impacts. *Bulletin of the American Meteorological Society,* 80, 1829-1852.

Box, G.E.P., and D.R. Cox, 1964. An analysis of transformations. *Journal of the Royal Statistical Society*, B26, 211-243.

Box, G.E.P. and G.M. Jenkins. (1976). *Time Series Analysis: Forecasting and Control*, San Francisco: Holden-Day.

Bunn, D.W. (1999). *Strategic Price Risk in Wholesale Power Markets*. Risk Publications.

Bunn, D.W. (2000). Forecasting Loads and Prices in Competitive Power Markets. *Proceedings of The IEEE*, Vol. 88, No. 2, pp. 163–169.

Clewlow, L. and C. Strickland. (2000). Energy Derivatives: Pricing and Risk Management. *Lacima Publications*. London, England, 246 pp.

Considine, G. (2000). *Introduction to Weather Derivates*, Weather Derivatives Group, Aquila Energy.

Ethier, R.G. (1999). Competitive Electricity Markets, Prices and Generator Entry and Exit. Ph.D. Dissertation, Department of Agricultural, Resource and Managerial Economics, Cornell University, Ithaca, New York.

Ethier, R.G. and T.D. Mount. (1999). Estimating the Volatility of Spot Prices in Restructured Electricity Markets. Working Paper, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, New York.

Hamilton, J.D. (1994). *Time Series Analysis.* Princeton University Press. Princeton, New Jersey.

Faruqui, A. and S. George, 2002. The Value of Dynamic Pricing in Mass Markets, Submitted to the *Electricity Journal.*

Mason, S.J., L. Goddard, N.E. Graham, E. Yulaeva, L. Sun, and P.A. Arkin, 1999. The IRI seasonal climate prediction system and the 1997/98 El Nino event. *Bulletin of the American Meteorological Society,* 80, 1853-1873.

Meza, F.J., D.S. Wilks, and S.J. Riha, 2002. Assessing the impacts of climatic variability on wheat yields by using crop simulation models and weather generators conditioned on El Nino phases. A case study for Chile's agricultural central valley. Preprints, Third Symposium on Environmental Applications, American Meteorological Society, 140-145.

Meza, F.J., D.S. Wilks, S.J. Riha, and J.R.Stedinger 2003. Value of perfect forecasts of sea surface temperature anomalies, for selected rain-fed agricultural locations of Chile. Agricultural and Forest Meteorology, submitted.

Meza, F.J., and D.S. Wilks, 2003. Value of climate forecasts based on seasonal average sea surface temperature anomalies, for selected agricultural rain-fed locations of Chile. *Agricultural and Forest Meteorology,* in preparation.

Mount, T.D. and S. Yoo. (2002). Designing Forward Markets for Electricity to Meet the Needs of Customers, presented at the Advanced Workshop in Regulation and Competition, Competitive Change in Network Industries, 21st annual Eastern Conference, Center for Research in Regulated Industries at Rutgers, Newport, Rhode Island, May 22-24.

Ning, Y. (2001). Modeling Spot Markets for Electricity and Pricing Electricity and Pricing Electricity Derivatives. Ph.D. Dissertation, Department of Applied Economics and Management, Cornell University, Ithaca, New York.

Ning, Y., T.D. Mount and D.S. Wilks (2002). Modeling the Effects of Seasonal Forecasts of Temperature on the Predictability of Spot Prices in Restructured Electricity Markets. Working Paper, Department of Applied Economics and Management, Cornell University, Ithaca, New York, in preparation.

Oren, S. (2001) Market Based Risk Mitigation: Risk Management vs. Risk Avoidance, Presented at a White House OSTP/NSF Workshop on Critical Infrastructure Interdependencies, June 14-15, Washington, DC.

Ramanathan, R. R., Engle, C.W.J. Granger, F. Vajod-Araghi and C. Brace. (1997). Short Run Forecasts of Electricity Loads and Peak*, Int. J. Forecasting*, Vol. 13, pp. 161-174.

Richardson, C.W. (1981). Stochastic simulation of daily precipitation, temperature, and solar radiation. *Water Resources Research* 17, 182-190

Rookley, C. (2000). WeatherDelta: A Weather based Approach to Contract Pricing & Risk Management, *World Power 2000*, Isherwood Production Ltd., Isherwood, England.

Taylor, J.W. and R. Buizza. (2000). Using Weather Ensemble Predictions in Electricity Demand Forecasting, Technical Memorandum No. 312 from the European Centre for Medium-Range Forecasts, Reading, United Kingdom.

Smith, L.A., M.S. Roulston, and J. von Hardenberg (2001). End to End Ensemble Forecasting: Towards Evaluating the Economic Value of the Ensemble Prediction System, Technical

Memorandum No. 336 from the European Centre for Medium-Range Forecasts, Reading United Kingdom.

Wilks, D.S. (1995). *Statistical Methods in the Atmospheric Sciences*, International Geophysics Series, Vol. 59, Academic Press, 464 pp.

Wilks, D.S., 1999a. Diagnostic verification of the CPC long-lead outlooks, 1995-1998. Preprints, 8th Conference on Climate Variations, Denver, CO. 166-171.

Wilks, D.S. (1999b). Simultaneous Stochastic Simulation of Daily Precipitation, Temperature and Solar Radiation at Multiple Sites in Complex Terrain. *Agricultural and Forest Meteorology*, 96, 85-101.

Wilks, D.S. (2000a). On interpretation of probabilistic climate forecasts. *Journal of Climate*, 13, 1965-1971.

Wilks, D.S. (2000b). Diagnostic verification of the Climate Prediction Center long-lead outlooks, 1995-1998. *Journal of Climate*, 13, 2389-2403.

Wilks, D.S., 2000c. Disaggregation of the CPC seasonal outlooks. Preprints, 15th Conference on Probability and Statistics in the Atmospheric Sciences, J83-J86.

Wilks, D.S., 2001. Space-time downscaling of probabilistic seasonal forecasts with a "weather generator". Proceedings, 26th Climate Diagnostics and Prediction Workshop, http://www.cpc.ncep.noaa.gov/products/outreach.

Wilks, D.S. 2002. Realizations of daily weather in forecast seasonal climate. *Journal of Hydrometeorology,* 3, 195-207.

Wilks, D.S., and C.M Godfrey 2000. Diagnostic verification of the IRI Net Assessment precipitation forecasts, 1997-1999. Proceedings, 25th Annual Climate Diagnostics and Prediction Workshop, 23-26 October 2000, Palisades, NY, 153-156.

Wilks, D.S. and C.M. Godfrey 2002a. Diagnostic Verification of the IRI Net Assessment Forecasts, 1997-2000*. Journal of Climate,* 15, 1369-1377.

Wilks, D.S. and C.M. Godfrey 2002b. Diagnostic verification of the IRI net assessment forecasts, 1997-2000. Preprints, 16th Conference on Probability and Statistics in the Atmospheric Sciences, American Meteorological Society, 31-36.

Wilks, D.S., and R.L. Wilby, 1999. The weather generation game: a review of stochastic weather models. *Progress in Physical Geography,* 23, 329-357.

Wu, D.J., P.R. Kleindorfer and J.E. Zhang (2000). Optimal Bidding and Contracting Strategies in the Deregulated Electric Power Market: Part I, HICSS-33 (CD ROM), 33rd Annual Hawaii International Conference on System Sciences, Restructuring the Electric Power Industry: Emerging Issues, Methods and Tools in the Emerging Technologies Track, Maui, Hawaii. January.

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*** Research activities and findings:**

Seasonal forecasts and Chilean agriculture:

Optimal use and economic value of seasonal forecasts for agricultural decisions in Chile was investigated. Management options for rainfed winter wheat, spring wheat, oats, potato, and sugar beets; including planting date, plant density, and fertilization rates were investigated. Both linear (risk-neutrality) and nonlinear (risk averse and risk-seeking behavior) utility function were modeled. The utilities of both perfect and simple (practically realizable) statistical forecasts of Nino 3.4 sea-surface temperatures, through their effect of growing season weather (primarily wetter seasons in El Nino years and drier seasons in La Nina Years), were investigated. Calculated economic value depends very sensitively on the location within Chile and the crop under consideration, but range from zero to more than $100/ha-yr in certain cases, even for the realistic imperfect forecasts. These are among the highest economic values for seasonal forecasts reported in the literature to date.

*** Presentations:**

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Wilks, D.S., 2002. Space-time downscaling of probabilistic seasonal forecasts with a "weather generator". Proceedings, 26th Climate Diagnostics and Prediction Workshop, http://www.cpc.ncep.noaa.gov/products/outreach.

Wilks, D.S., and C.M. Godfrey, 2002. Diagnostic verification of the IRI net assessment forecasts, 1997-2000. Preprints, 16th Conference on Probability and Statistics in the Atmospheric Sciences, American Meteorological Society, 31-36.

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Meza, F.J., and D.S. Wilks, 2003. Value of operational forecasts of seasonal average sea surface temperature anomalies, for selected rain-fed

agricultural locations of Chile. Agricultural and Forest Meteorology, submitted.

Meza, F.J., and D.S. Wilks 2003. Value of seasonal forecasts of sea surface temperature anomalies for potato fertilization management. A case study for Valdivia Chile. Agricultural Systems, submitted.

Wilks, D.S., 2002 Realizations of daily weather in forecast seasonal climate. Journal of Hydrometeorology, 3, 195-207.

Wilks, D.S., and C.M. Godfrey, 2002. Diagnostic Verification of the IRI Net Assessment Forecasts, 1997-2000. Journal of Climate, 15, 1369-1377.